

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
24 May 2007 (24.05.2007)

PCT

(10) International Publication Number  
**WO 2007/057064 A1**

(51) International Patent Classification:

**G06T 7/00** (2006.01) **G06T 5/10** (2006.01)

(21) International Application Number:

PCT/EP2006/008358

(22) International Filing Date: 25 August 2006 (25.08.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

11/282,954 18 November 2005 (18.11.2005) US

(71) Applicant (for all designated States except US): **FOTO-NATION VISION LIMITED** [IE/IE]; Galway Business Park, Dangan, Galway (IE).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **STEINBERG, Eran** [IL/US]; 137 Granville Way, San Francisco, CA 94127 (US). **PRILUTSKY, Yury** [US/US]; 1626 Shoal Drive, San Mateo, CA 94404 (US). **POSOSIN, Alexei** [MD/IE]; 28 Arus na Tra, Cois Cuain, Dr. Colohan Road, Galway (IE). **BIGIOI, Petronel** [RO/IE]; 57 Sceilg Ard, Headford Road, County Galway (IE). **CIUC, Mihai** [RO/RO]; Str.

Latea Gheorge, nr. 17, Bloc C60, Scara 1, Etaj 7, Apt. 45 Sector 6, R-061664 Bucharest (RO). **CORCORAN, Peter** [IE/IE]; Cregg, Claregalway, Galway (IE).

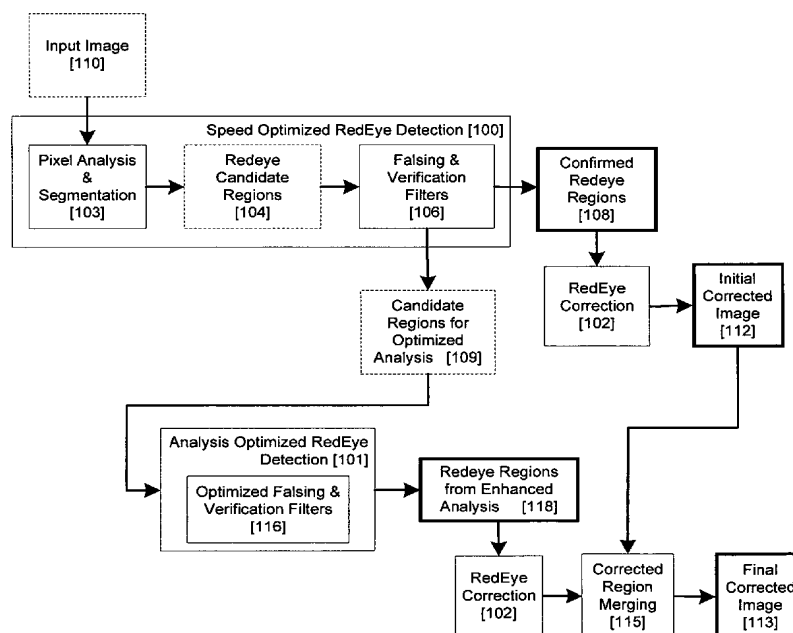
(74) Agents: **BOYCE, Conor** et al.; F. R. Kelly & Co., 27 Clyde Road, Ballsbridge, Dublin 4 (IE).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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(54) Title: TWO STAGE DETECTION FOR PHOTOGRAPHIC EYE ARTIFACTS



(57) Abstract: A digital image acquisition device is for acquiring digital images including one or more preview images. A face detector analyzes the one or more preview images to ascertain information relating to candidate face regions therein. A speed-optimized filter produces a first set of candidate red-eye regions based on the candidate face region information provided by the face detector.

WO 2007/057064 A1



**Published:**

— with international search report

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

## TWO STAGE DETECTION FOR PHOTOGRAPHIC EYE ARTIFACTS

The present invention relates to digital image processing, and more particularly to a method and apparatus for detection and correction of red-eye defects and/or other artifacts in an acquired digital image.

Redeye is the appearance of an unnatural reddish coloration of the pupils of a person appearing in an image captured by a camera with flash illumination. Redeye is caused by light from the flash reflecting off blood vessels in the person's retina and returning to the camera.

A large number of image processing techniques have been proposed to detect and correct redeye in color images. In general, these techniques typically are semi-automatic or automatic. Semi-automatic redeye detection techniques rely on human input. For example, in some semi-automatic redeye reduction systems, a user must manually identify to the system the areas of an image containing redeye before the defects can be corrected.

Many automatic redeye reduction systems rely on a preliminary face detection step before redeye areas are detected. A common automatic approach involves detecting faces in an image and, subsequently, detecting eyes within each detected face. After the eyes are located, redeye is identified based on shape, coloration, and brightness of image areas corresponding to the detected eye locations. In general, face-detection-based automatic redeye reduction techniques have high computation and memory resource requirements. In addition, most of the face detection algorithms are only able to detect faces that are oriented in an upright frontal view. These approaches generally do not detect faces that are rotated in-plane or out-of-plane with respect to the image plane.

A redeye filter process is illustrated in Fig 1(a). An input image is first analyzed by a speed optimized redeye detection stage 100 at a pixel level 103 and segmented into candidate redeye regions 104. A further series of falsing and verification filters 106 are then applied to the candidate regions and a set of confirmed redeye regions 108 is thus determined. A correction filter (pixel modifier) 102 is next applied to the confirmed regions and a final image 112, corrected for redeye, is generated.

United States patent 6,407,777 to inventor DeLuca discloses in-camera detection and correction of redeye pixels in an acquired digital image, while US published patent application 2002/0176623 to inventor Steinberg discloses automated real-time detection and

correction of redeye defects optimized for handheld devices (each of these is assigned to the same assignee as the present application, as are US applications serial nos. 10/919,226, filed August 16, 2004, 10/772,092, filed February 4, 2004, 10/773,092, filed February 4, 2004, and 10/635,918, filed August 5, 2003). US published patent applications 2005/0047655 and  
5 2005/0047656 to Luo et al disclose techniques for detecting and correcting redeye in a digital image and in embedded systems, respectively.

Within an image acquisition subsystem such as is embodied in typical digital cameras, a peak computing load and resource requirements occur around the time of image acquisition. Upon receiving an image acquisition request from the user the main embedded  
10 processing system refines the image focus and exposure to achieve an optimal main acquired image. This image, in turn, is off-loaded from the main optical sensor of the camera and subjected to further image processing to convert it from its raw format (e.g. Bayer) to a conventional color space such as RGB or YCC. Finally the acquired image is compressed prior to saving it on a removable storage medium such as a compact flash or multimedia card.

15 The time taken by the camera to recover from the acquisition of a first image and reinitialize itself to capture a second image is referred to as the "click-to-click" time. This parameter is used in the comparison and marketing of modern digital cameras. It is desired for manufacturers to minimize this "click-to-click" time. Thus, it is desired that any additional image processing, such as redeye filtering, which is to be added to the main image  
20 acquisition chain should be highly optimized for speed of execution in order to minimize its impact on the click-to-click time of the main system. Such a redeye filter typically compromises its overall performance in terms of accuracy of detection of redeye defects and quality of image correction.

An alternative would be to wait until after the main image has been acquired and  
25 perform the redeye filtering at a later time when the camera may execute the filter as a background process, or to perform the redeye filtering off-camera on a desktop PC or printer. There can be drawbacks to this alternative approach, though. First, images are displayed on the acquiring device, immediately after acquisition, with uncorrected redeye defects. Second, when images are accessed in playback mode, there is a further delay while images are post-  
30 processed before an image can be displayed. Both drawbacks would create a negative impression on end users.

Further, as most digital cameras store images using lossy compression techniques there can be additional disadvantages with respect to image quality as images are decompressed

and recompressed in order to perform redeye detection and correction processes in playback or background modes. Such loss of image quality may not become apparent until later when a user wishes to print an image and it is too late to reverse the process.

5 If redeye processing is delayed until the images are loaded onto another device, such as a desktop PC or printer, there can be further disadvantages. First, meta-data relating to the acquiring device and its state at the time the image was acquired may not be available to the redeye filter process. Second, this post-processing device performs redeye filtering on the entire image; so that for an embedded device such as a printer that may be relatively constrained in terms of CPU cycles and processing resources for its primary post-processing activity, it would be desirable to optimize the performance of the full redeye filter. It is generally desired to optimize the detection of red-eye defects in digital images for embedded image acquisition and processing systems.

15 A digital image acquisition device is provided. An imaging optic and detector is for acquiring digital images including one or more preview images and a main image. A face detector module is for analyzing the one or more preview images to ascertain information relating to candidate face regions therein. An image generating module is for programming the processor to generate a sub-sampled version of the main image. A first speed-optimized red-eye filter is for programming the processor to produce a first set of candidate red-eye regions in a sub-sampled version of the main image based on the candidate face region information provided by the face detector.

20 An image encoder is for encoding the acquired image. An image compressor is for compressing the main image.

An image store memory is for storing therein said encoded image in association with said first set of candidate red-eye regions for later image processing of the encoded image.

25 An analysis-optimized red eye filter is for later analysis of a full resolution version of the main image based in part on the previous analysis.

A display is for displaying an image processed by said first speed-optimized red-eye filter.

30 A signal connection is for transferring images to a PC or other microprocessor-based device, or both, for further image processing.

The face detector may include a search module for detecting candidate face regions and a tracking module for predicting and confirming candidate face regions.

The one or more preview images may include a sub-sampled version of an acquired image.

The candidate face region information includes (i) a list of one or more candidate face regions; (ii) a set of data associated with one or more candidate face regions and statistical data derived from a history of the one or more candidate face regions; or (iii) a predicted location for one or more candidate face regions; or (iv) combinations thereof.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1(a) illustrates a redeye process.

Figure 1(b) illustrates a redeye process according to a preferred embodiment.

Figure 1(c) illustrates a redeye process according to an alternative embodiment.

Figure 2(a) illustrates an embodiment within a digital image acquisition device.

Figure 2(b) illustrates an embodiment wherein analysis-optimized redeye filtering is performed on a separate device from an acquiring device.

Figure 3(a) illustrates a process according to an embodiment whereby a speed-optimized redeye detector is applied to a partially compressed DCT block image.

Figure 3(b) is a workflow diagram of an illustrative embodiment of an improved in-camera redeye detection component employing a redeye DCT prefilter.

Figure 3(c) is a workflow diagram of an illustrative embodiment of the redeye DCT prefilter.

Figure 3(d) illustrates segmentation of a redeye DCT prefilter.

Figure 3(e) shows a 4-DCT block neighborhood.

Figure 4(a) illustrates eye regions mapped onto a rectangular grid.

Figure 4(b) illustrates the approximate color which will be recorded by a DC coefficient of each DCT block after the image of Figure 4(a) is transformed into the DCT domain.

Figures 4(c), 4(d) and 4(e) illustrate DCT blocks from Figure 4(a) that can be identified with the colors of a redeye candidate region, an eye-white region and a skin color region, respectively, through the use of an inclusive color determining filter method;

Figure 5 illustrates a functional implementation of a modified redeye filtering process according to another embodiment.

Figure 6(a) illustrates an original defect region stored in a header and a corrected defect region applied to a main image body.

Figure 6(b) illustrates a corrected defect region stored in the header and the original defect region remaining uncorrected in the main image body.

Figure 6(c) illustrates an original defect region and at least one alternative corrected defect region stored in the header and the optimally determined corrected defect region applied to the main image body; and.

Figure 7 illustrates a functional implementation of a preferred further embodiment of a redeye filtering process.

A two-stage redeye filtering process is provided whereby a speed optimized filter performs the initial segmentation of candidate redeye regions and optionally applies a speed-optimized set of falsing/verification filters to determine a first set of confirmed redeye regions for correction. Some of the candidate regions which are rejected during the first stage are recorded and re-analyzed during a second stage by an alternative set of analysis-optimized filters to determine a second set of confirmed redeye regions.

Optionally, the first set of confirmed redeye regions may be passed through the second stage analysis-optimized filters.

In an alternative embodiment, the second stage filter may incorporate an enhanced correction filter which may be optionally applied to the first set of confirmed redeye regions.

A process is provided including implementing a two-stage redeye filter wherein a first redeye filter process, which is optimized for speed, is combined with a second redeye process which is optimized for accurate image analysis. The advantages of a redeye filter implemented within a main image acquisition chain are combined with those of a redeye filter implemented in background/playback mode, while disadvantages generally associated with each of these two approaches are reduced or eliminated.

A red eye process in accordance with a preferred embodiment is illustrated in Figure 1(b). An input image 110 is processed by a pixel analyzer 103, segmented into a set of candidate regions 104 and subsequently passed through a set of falsing & verification filters 106. These components form a speed optimized redeye detection filter 100 corresponding generally to the filter 100 of Figure 1(a), except that in the embodiment illustrated at Figure 1(b), filter 100 is modified so that candidate redeye regions which, instead of being ultimately classified as false positives, based on their size or probability being below a predetermined threshold are saved as candidate regions 109 for a subsequent optimized analysis 101.

Thus, in this embodiment the falsing & verification filters 106 generates a set of secondary candidate regions 109 in addition to the set of confirmed redeye regions 108. The

set of secondary candidate regions may include members of the original candidate region set 104, which could be neither confirmed nor eliminated by the speed optimized redeye detection process 100. It may also include combined candidate regions in close proximity to each other.

5           This set of candidate regions 109 is saved either in a RAM buffer, or in non-volatile memory depending on the implementation of the embodiment. Where the data is saved in RAM (or volatile) memory, the image acquisition system applies the second stage redeye filter to the image prior to powering down. The preferred form of storage is in non-volatile memory, or on a removable media card. In other embodiments this data may be stored in the  
10 image header with the part-processed image itself.

          In this embodiment, a second stage, analysis optimised redeye filter 101 is next applied to the secondary set of candidate regions 109. During the analysis optimized detection process 101, the saved candidate regions 109 are preferably further analyzed at a higher resolution than during the speed optimized process. Thus, the filter 101 includes an analysis  
15 optimized set of falsing and verification filters 116, which differ either in their nature or in their operating parameters from the falsing and verification filters 106 employed in the speed optimized analysis. Nonetheless, it will be appreciated that it may be useful to perform one or more intermediate stages of optimized analysis at increasing image resolutions. This will depend on the hardware capabilities of the imaging appliance and the resources available  
20 within the image processing subsystems of the imaging appliance.

          Second stage analysis may occur in response to a variety of external events. For example, a user may initiate image playback causing this filter 101 to be applied. Alternatively, a camera may signal that it has been idle for a predetermined interval and thus background redeye processing may be initiated. Where a camera can determine its motion  
25 from auto-focus data, e.g., when a camera is idle such that image focus does not change for a predetermined interval and no user input is received, background image processing including stage-two redeye filtering may be initiated.

          After a set of confirmed redeye regions 118 is determined by the second stage redeye filter 101, a correction filter (pixel modifier) 102 is applied and these corrected regions are  
30 merged 115 with the initial corrected image 112 to generate a final corrected image 113.

          An alternative embodiment is illustrated in Fig 1(c) which differs from the embodiment of Fig 1(b) in that a single correction filter (pixel modifier) 102b is applied after the second stage redeye filter 101, rather than merging the initial corrected image 112 with



the corrected regions determined by the stage-two filter 101. The filter 102b corrects both the original confirmed redeye regions 108 and the second stage confirmed redeye regions 118 to produce the final corrected image 113.

Fig 2(a) illustrates an embodiment within a digital image acquisition device. The speed optimized redeye filter 411 may contains both detection 411-1, 411-2 & 411-4 and, optionally, correction 411-3 processes. Similarly, the analysis optimized redeye filter 412, which may operate as a background process 403, performs additional refinements to the initial determinations and corrections of the speed optimized filter 411. Data related to these initial determinations is provided by the redeye filter metadata 410-5 which is stored with the acquired image 410-2 in an image store 410.

Fig 2(b) illustrates a variation on the embodiment of Fig 2(a) wherein the analysis optimized redeye filter is performed on a separate device 400 to the original acquiring device. This may be, for example, a desktop PC, or a printer. In other embodiments the camera may connect directly to a network or web service. The image data transfer means 404a, 404b may be either a point-to-point communications link between the two devices. A removable storage media may be physically exchanged between the two devices, or alternatively both devices may be connected to a common network such as the internet. In other embodiments, the redeye filter metadata 410-5 may be incorporated with the main image data 410-2 by adding the metadata to the JPEG header (see Figure 3(a)). Background redeye filters may operate on both the original acquiring device 400 and a separate device 400'. Supporting multiple redeye filters of increasing sophistication can involve exchange and storage of complex and detailed metadata with the image being analyzed and corrected.

For an exemplary, non-exhaustive list of some typical filters that may be found in either the speed or analysis-optimized redeye filters 411, 412, see US published application No. 10/976,336, filed October 28, 2004, which is assigned to the same assignee as the present application.

In the embodiments above, speed optimized redeye detection 100 is preferably applied to a sub-sampled input image. The confirmed redeye regions 108 from this speed optimized redeye detection 100 are passed to a redeye correction module 102/102a. The corrected redeye image 112 can be displayed on a low-resolution viewing screen of a digital camera immediately after the image acquisition process providing the user with a redeye corrected image almost instantly. However, although this initial corrected image 112 may be adequately corrected, for example, where it is a portrait-style image in which a face occupies most of an

image or where large high probability red-eye regions exist, it may not be adequately corrected for images including a large groups of persons, where the candidate redeye regions are smaller or less certain. Accordingly, the second analysis optimized redeye filtering process 101 is preferably implemented after image acquisition but prior to final image 113 display on a larger viewer, or image printing. The analysis optimized redeye detection process 101 and correction process 102 may be advantageously delayed until such high resolution viewing or printing is desired by the end user.

In the embodiments of Figures 2(a) and 2(b), the sub-sampled versions of the main image or well as uncorrected full size versions of the main image may be provided directly from main image acquisition device hardware 402 rather than needing to explicitly sub-sample a decoded full size main image.

As in the case of Figure 1(c), image correction need not be performed on images within the acquisition chain and can in fact be performed in the background on acquired images for which speed optimised redeye detection has been performed in the acquisition chain. This is advantageous in many image acquisition appliances where image compression is often implemented in hardware as part of the main image acquisition chain 401. In this embodiment, only the detection process is actually performed in the acquisition chain. A speed optimized correction or a full analysis optimized redeye filter may be subsequently selected in playback mode either based on a predetermined setting within the camera, or on a user selection at the time of image playback/viewing.

In the embodiment of Fig 3(a), an acquired raw image 402 is partially processed 404 before being provided to DCT compression block 408-1. This block provides a sub-sampled version of the acquired image and, although not shown, this can be provided to the image store 410 as explained above. A speed optimized redeye detector 428 is then applied to the partially compressed DCT block image and DCT red-eye candidate regions both corrected and suspected uncorrected regions are output for storage in the store 410. An advantage of applying speed optimised correction at DCT block level, rather than at the pixel level, is that the need for an explicit image subsampling step is avoided, yet the benefits of applying redeye analysis to a sub-sampled image as detailed in the prior art cited herein are retained.

The regions output by the DCT prefilter 428, incorporated in the main image acquisition chain 401, can advantageously allow much of the DCT block stream to be bypassed without being processed when an image is subsequently corrected by a filter such as a background filter module 426. This allows either much faster or more detailed analysis and

filtering of the DCT blocks which are determined to require processing by an analysis optimized redeye filter 406. Those skilled in the art will realize that further embodiments are possible which separate aspects of both the DCT prefilter and the otherwise conventional type redeye filter 406 between the main image acquisition chain, 401 and a background redeye  
5 detection and correction process 426.

Figure 3(b) shows in more detail the operation of the redeye DCT prefilter 428. This particular example illustrates how the DCT prefilter can integrate with the main image acquisition, processing and compression chain, 402, 404 and 408 of Fig 3(a). The DCT image to be filtered is first loaded into memory 902 after which the main DCT prefilter 428 is  
10 applied. This has three main stages. First, the DCT blocks of the image are scanned 904 and the relevant DCT coefficients are extracted. Depending on the sophistication of the filter, perhaps only the DC components of each DCT block may be utilized in the subsequent analysis. Alternatively, some of the AC components may be extracted in order to allow some texture or sharpness/blur determination as part of the prefilter operation.

In a second principle stage of the DCT prefilter 428, the DCT blocks are segmented and grouped 906 based on a plurality of criteria determined from the coefficients extracted at step 904. A region based analysis is performed 907 in order to determine the final candidate redeye groupings. It is next determined if there are any valid candidate grouping 908 and if not the normal JPEG compression process is resumed 408-2. If candidate regions are  
20 determined 908 then a bounding region is determined for each region 910 which is sufficiently large to include various eye-region features which may be used as part of a main redeye filter process 411/412 of Figure 3(a). If the certainty of the region being a flash eye defect is high enough, a bounding box region may be decompressed to bitmap format 912 and a speed optimized redeye filter chain 914 may be applied to correct that region of the main  
25 image 914. The corrected regions in bitmap space are next mapped to an integer number of 8x8 block boundaries and are recompressed 918 and subsequently overwritten 920 onto the DCT domain. Finally, normal JPEG compression is resumed 408-2. As mentioned previously each of the corrected region boundaries and suspected region boundaries may be output for use in later analysis optimized detection and correction.

Fig 3(c) shows the region based analysis 907 of Fig 3(b) in more detail. First, the DCT coefficients are read 930 from a DCT image in temporary memory store. These coefficients are then preprocessed into a set of criteria tables 932. Each table is preferably a numeric table of size NxM where there are NxM DCT blocks in the image being analyzed. As examples,

one such table will contain the red chrominance component normalized to emphasize a colour range associated with flash eye defects and derived from the DC coefficients for the luminance (Y) and red chrominance (Cr) components of each DCT block. Another table may contain differential values derived from neighboring DCT blocks and used in edge detection. Yet another table may contain variance values calculated across a set of neighboring DCT blocks. Those skilled in the art will realize that as an implementation of the DCT prefilter becomes increasingly sophisticated that multiple additional criteria may be incorporated into the algorithm.

After the calculations required for each criteria table have been completed 932 they are copied into temporary storage 933 and the prefilter algorithm will next perform a filtering and segmentation step 907 for each of the plurality of criteria tables. This particular step is further detailed in Fig 3(d) below. Now the prefilter has determined a plurality of sets of DCT block grouping based on the segmentation analysis of a plurality of criteria tables. These groupings are sorted and analyzed to determine a final set of flash defect candidate regions.

This region-based analysis 936 is comprised of a number of alternative techniques which will be known to those skilled in the art. In particular, we mention that regions may be combined both in inclusive, exclusive and less frequently in mutually exclusive combinations 936-1. An alternative approach to region-based analysis will employ template matching 936-2. An example is provided in US 5,805,727 to Nakano. A sub-region is matched within a DCT image using both coarse and fine template matching techniques based on the DC coefficients of the DCT blocks within the image.

A component of the region based analysis is a re-segmentation engine 92-6 which is responsible for analyzing larger regions which may, in fact, be two distinct overlapping regions, or clusters of smaller regions which may, in fact, be a single larger region. Then once the region based analysis 936 is completed a final LUT containing the list of determined flash defect candidate regions is obtained and written to system memory.

Figure 3(d) shows the segmentation step 907 of the redeye DCT prefilter in more detail. The next preprocessed criteria table to be processed by the segmentation process is first loaded 950 and the labeling LUT for the region grouping process is initialized 952. Next the current DCT block and DCT block neighborhoods are initialized 954.

Figure 3(e) shows a diagrammatic representation of a 4-DCT block neighborhood 992 containing the three upper DCT blocks and the DCT block to the left of the current DCT block 994, which is cross-hatched in Figure 3(e). This 4-block neighborhood 992 is used in

the labeling algorithm of this exemplary embodiment. A look-up table, LUT, is defined to hold correspondence labels.

Returning to step 954 we see that after initialization is completed the next step for the workflow of Figure 3(d) is to begin a recursive iteration through all the elements of the current criteria table in a raster-scan from top-left to bottom-right. The workflow next determines if the current criteria table value, associated with the current DCT block satisfies membership criteria for a candidate redeye region 958. Essentially this implies that the current criteria table value has properties which are compatible with a flash eye defect. If the current criteria table value satisfies membership criteria for a segment 958, then the algorithm checks for other member DCT blocks in the 4-block neighborhood 960. If there are no other member blocks, then the current block is assigned membership of the current label 980. The LUT is then updated 982 and the current label value is incremented 984. If there are other member blocks in the 4-block neighborhood 960 then the current block is given membership in the segment with the lowest label value 962 and the LUT is updated accordingly 516. After the current block has been labeled as part of a flash-eye defect segment 962 or 980, or has been categorized as not being a member of a candidate defect region during step 958, a test is then performed to determine if it is the last DCT block in the image 966. If the current block is the last block in the image then a final update of the LUT is performed 970. Otherwise the next criteria table value is obtained by incrementing the current block pointer 968 and returning to step 958 and is processed in the same manner. Once the final DCT block is processed and the final LUT completed 970, all of the blocks with segment membership are sorted into a labeled-segment table of potential eye-defect segments 972. Another test is then made to determine if this is the last criteria table to be processed 966 and if that is the case then control is passed to the region based analysis step of Figure 3(c) 936. Otherwise the block segmentor returns to step 950 and loads the next criteria table for processing.

A number of alternative techniques can advantageously be adapted for use within the redeye DCT prefilter. US 5,949,904 to Delp discloses querying image colors within a DCT block. In particular it allows the determination of color within the DCT block from the DC coefficient of the DCT alone. Thus from a knowledge of the DC coefficients alone color matching can be achieved. US 6,621,867 to Sazzad et al discloses determining the presence of edges within DCT blocks based on differences between the DC coefficients in neighbouring DCT blocks.

Now additional image qualities such as texture and image sharpness/blur can be determined through an analysis of additional AC components within a DCT block. Examples of such analysis techniques are described in US patent application No. 2004/0120598 to Feng and US patent application No. 2004/0057623 to Schuhurke et al.

5        Alternative DCT block segmentation techniques may be employed in other embodiments, and specifically techniques described in US 6,407,777 to DeLuca, US 6,873,743 to Steinberg, and US patent applications 2005/0047655 and 2005/0047656 to Luo et al.

10        In Figure 4(a) we show an example of how an outline color template can be constructed for redeye regions. Fig 4(a) shows an eye regions mapped onto a rectangular grid. Each block of the grid 201 corresponds to an 8x8 pixel block. The main redeye defect 204 is typically surrounded by an iris region 203 and an additional eye-white region 202 and the boundary of the main redeye region, 206 as determined by a redeye filter.

15        Next, in Figure 4(b) we show the approximate color which will be recorded by the DC coefficient of each DCT block after the image in Fig 4(a) is transformed into the DCT domain. The colour combinations shown in Fig 4(b) are as follows: R is a reddish hue indicative of a flash-eye defect phenomenon; S is a hue indicative of a skin colour; W: indicates a whitish colour associated with the eye-white region; I: is the Iris colour of the eye which can vary significantly from person to person; WS: indicates a block with mixed skin and eye-white; RW: is a block with mixed redeye and eye white; and RI: has a hue which is a mix of red and the Iris color. Now if sufficiently inclusive color filtering is applied to these image blocks it is possible to determine directly from the DC coefficients of the DCT domain image a color map for a typical redeye. Figure 4(c) illustrates a region which will be determined as red if an inclusive color filter is used. Figures 4(d) and 4(e) illustrate this for  
20        eye white and skin color regions surrounding the flash eye defect region. This data can, for example, be used to build a set of color templates for a flash eye defect region. By applying other conventional techniques it is possible to determine DCT blocks which contain sharp edges, or transitions between color regions. This can provide additional information to improve the DCT prefilter detection process.

30        A potential disadvantage in the embodiment of Figure 3(a) is that it requires the entire image to be decompressed in order to perform the second-step redeye filtering process. As most cameras use JPEG compression which is lossy it is desirable for certain embodiments to

implement a lossless embodiment which allows a two-stage redeye process to be applied within an image acquisition appliance without loss of image quality.

Accordingly, Figure 5 illustrates a functional implementation of modified redeye filtering process which allows an analysis optimized redeye detection and correction to occur in playback mode, without loss of image quality. This also allows complex post-processing, to be implemented in incremental steps. Thus, when a camera is idle with respect to user activity, yet is still switched on it may load and commence processing of an image. When user activity recommences the camera can recompress and save the image being processed prior to responding to the user. As the embodiment described below allows lossless saving and restoration of a image within the camera, it thus facilitates incremental process of an image which is not limited to redeye, but may be applied likewise to other in-camera methods such as face detection or recognition.

Various means of sensing user activity may be alternatively employed. One example includes detecting camera motion and optionally correlating this with other in-camera functions such as an autofocus subsystem and a user-interface subsystem. A camera may also incorporate a power-saving mode which determines that the camera has been inactive long enough to disable certain subsystems. When such a mode is activated by user inactivity then additional background image processing can be initiated without interfering with the use of the appliance by the user.

Returning to Figure 5, an embodiment is illustrated which incorporates a speed-optimized redeye filter 411 in the main image acquisition chain 401. In this exemplary embodiment, the speed optimization of the filter is achieved by implementing a minimal set of falsing and validation filters and no correction process is applied during the main image acquisition chain. In alternative embodiments the speed optimization techniques described in relation to embodiments above may optionally be incorporated or substituted.

After an image is analyzed by this speed optimized redeye filter 411 it is subsequently compressed 427-1 and stored 410. In addition data relating to the location of candidate redeye regions and false positives is recorded and associated with the stored image.

Now when the camera can initiate background processing, as described above, or when the user enters playback mode and selects an image for viewing it will be partially decompressed 433 from JPEG to DCT block form. As this decompression step is lossless there is no loss of quality to the main image which is temporarily stored in memory and passed to a DCT region decompressor 430. This DCT region decompressor uses the data

stored and associated with the original image to determine the specific DCT blocks which contain candidate redeye regions, and, optionally, false positive regions which may benefit from additional detection processing if sufficient time & system resources are available.

Each decompressed DCT region is then incrementally filtered by one or more redeye  
5 filters to determine corrections which should be applied to said DCT image block.

In certain embodiments, DCT blocks may be decompressed to bitmap format and filtered as a pixel block. In other embodiments adjacent, non-candidate DCT blocks may be included in the decompression 430 and filtering 412 processes. Once a decompressed DCT block region, which may include multiple DCT blocks, has been corrected by the redeye filter  
10 412 then the corrected DCT image segment is passed onto a DCT block matching module 416 which, in addition to checking the alignment of DCT blocks will also check the integration of the corrected DCT blocks within the partially decompressed and temporarily stored DCT block image. When all candidate DCT blocks and any adjacent DCT blocks included in the redeye filter analysis have been corrected they are overwritten onto the  
15 partially decompressed and temporarily stored DCT block image by a DCT region overwriter 418 module. The partially decompressed and temporarily stored DCT block image is next passed to the DCT to JPEG image compression module 427-1 and is losslessly compressed back to JPEG format.

Note that in this way the only regions of the image which are decompressed using  
20 lossy techniques are those identified by the speed optimized redeye filter 411 in the image acquisition chain. As these image regions are to be corrected the effect of lossy decompression and recompression on them will thus be negligible.

Several further embodiments can be identified. These include (i) saving a copy of the original defect region prior to overwriting the DCT blocks which contain the image defect in  
25 the temporary copy of the DCT image. This alternative embodiment supports lossless restoration of the original image. The saved original DCT block region containing the defect can be stored within the header of the JPEG image. In US 6,298,166 to Ratnakar et al., watermark data is incorporated in the image. Thus the corrected image can contain a copy of any original uncorrected regions. Alternatively (ii) multiple alternative correction algorithms  
30 can be employed and these may be temporarily copied for later storage in the JPEG header for later selection by an end user through a user interface, either on the camera or subsequently in a computer based image processing application. The overwriting step is optional. If it is used, then certain image analysis criteria can be applied as additional processing either



immediately prior to overwriting, or as an integral part of detecting or correcting red-eye or combinations thereof.

Further aspects of these embodiments are illustrated in Figures 6(a)-(c). Figure 6(a) illustrates an example of the original defect region 506 stored in the header 504 and the  
5 corrected defect region 508 applied to the main image body 502. Figure 6(b) illustrates an example of the corrected defect region 508 stored in the header 504 and the original defect region 506 remaining uncorrected in the main image body 502. Figure 6(c) illustrates an example of the original defect region 506 and at least one alternative corrected defect region 508-2 stored in the header 504 and the optimally determined corrected defect region 508-1  
10 applied to the main image body 502. The graphical representations of “corrected” and “uncorrected” eye regions used in Figures 6(a)-(c) is for illustrative purposes; while graphical eye-regions preferably actually represents a transformed block of DCT coefficients.

In other embodiments, the performance of the fast red-eye filter can be further improved by selectively applying it to a limited set of regions within the acquired image. As it  
15 is generally impractical to implement extensive image analysis during the main image acquisition chain, these regions are preferably determined prior to the initiation of the main image acquisition.

One convenient approach to pre-determine image regions which have a high probability of containing red-eye candidates is to perform pre-processing on a set of preview  
20 images. Many state-of-art digital cameras acquire such a stream of images captured at video rates of 15-30 frames per second (fps) at a lower resolution than that provided by the main image acquisition architecture and/or programming. A set of 320x240, or QVGA images is typical of many consumer cameras and the size and frame-rate of this preview images stream can normally be adjusted within certain limits.

In one embodiment, as illustrated in Figure 7, the digital camera includes a face  
25 detector (600) which operates on the preview image stream (410-3). The face detector may have two principle modes: (i) a full image search mode to detect (and confirm) new face-candidate regions (601)); and (ii) a main tracking mode which predicts and then confirms the new location of existing face-candidates in subsequent frames of the image stream and  
30 compiles statistical information relating to each such confirmed candidate region. Both modes can employ a variety of methods including face detection, skin region segmentation, feature detection including eye and mouth regions, active contour analysis and even non-image based inputs such as directional voice analysis (e.g. US 2005/0147278 to Rui et al which describes a

system for automatic detection and tracking of multiple individuals using multiple cues). As the first mode, hereafter referred to as the “seeding mode” is applied to the entire image, it is computationally more intensive and is only applied occasionally, e.g., every 30-60 image frames. As such, new faces appearing in the image will still be detected within a couple of  
5 seconds which is sufficient for most consumer applications. The second mode is preferably applied to every image frame, although not all of the analysis cues may be applied on every frame.

Thus in normal operation only the output(s) from the second operational mode of a face tracker algorithm will be available after every frame of the preview image stream. There  
10 may be three principle outputs from this second mode: (i) a list of candidate face regions which are confirmed to still contain faces; and/or (ii) a set of data associated with each such confirmed face region including its location within that frame of the image and various additional data determined from a statistical analysis of the history of said confirmed face region; and/or (iii) a predicted location for each such confirmed face region in the next frame  
15 of the preview image stream. If item (ii) is used, item (iii) can be optional as sufficient data may be provided by item (ii) for a determination of predicted location.

These outputs from the preview face detector (600) enable the speed optimized red-eye detector 411 to be applied selectively to face regions (601) where it is expected that a red-eye defect will be found.

20 Techniques are known wherein a face detector is first applied to an image prior to the application of a red-eye filter (e.g. US 20020172419 to Lin et al; US 20020126893 to Held et al; US 20050232490 to Itagaki et al and US 20040037460 to Luo et al.). We emphasize that, under normal circumstances, there is not sufficient time available during the main image acquisition chain, which is operable within a digital camera to allow the application of face  
25 detector prior to the application of a red-eye filter. The present embodiment overcomes this disadvantage of the prior art by employing the predictive output of a face tracker module (600). Although the size of the predicted region will typically be larger than the size of the corresponding face region, it is still significantly smaller than the size of the entire image. Thus, advantages of faster and more accurate detection can be achieved within a digital  
30 camera or embedded image acquisition system without the need to operate a face detector (600) within the main image acquisition chain.

Note that where multiple face candidate regions (601) are tracked, then multiple predicted regions will have the speed-optimized red-eye filter applied.

## Claims:

1. A digital image acquisition device comprising:
  - 5 (a) an image acquisition device comprising:
    - (i) an imaging optic and detector for acquiring an image;
    - (ii) a first speed optimized filter for producing a first set of candidate red-eye regions for an acquired image; and
    - (iii) an image encoder for encoding said acquired image; and
  - 10 (b) an image store memory for storing therein said encoded image in association with said first set of candidate red-eye regions for later image processing of said encoded image.
2. A device according to claim 1 wherein said first speed-optimized filter is configured to operate on a low resolution version of said acquired image.
- 15 3. A device according to claim 2 wherein said first speed-optimized filter is configured to operate on a sub-sampled version of said acquired image.
- 20 4. A device according to claim 2 wherein said image acquisition device is configured to perform a Discrete Cosine Transformation (DCT) of an acquired image of  $N \times M$  pixels to produce an array of  $X \times Y$  DCT blocks, where  $X$  and  $Y$  are less than  $N$  and  $M$  respectively, and wherein said first speed-optimized filter is configured to operate on DCT characteristics of said DCT blocks.
- 25 5. A device according to claim 4 in which said filter is configured to operate on the chroma coefficients of said DCT characteristics.
6. A device according to claim 4 in which said filter is configured to operate on the DC coefficients of said DCT characteristics.
- 30 7. A device according to claim 4 wherein said image compressor is configured to produce a lossy encoded image from said DCT blocks.

8. A device according to claim 7 wherein said encoded image comprises a JPEG image.
- 5 9. A device according to claim 8 wherein said image compressor is configured to store said first set of candidate red-eye regions in a header or a footer, or both, of said JPEG image.
- 10 10. A device according to claim 4 wherein said first set of candidate red-eye regions comprises a set of DCT block identifiers.
11. A device according to claim 1 further comprising a first image correction module for correcting one or more of said first set of candidate red-eye regions in an acquired image prior to display of said corrected image on said display.
- 15 12. A device according to claim 11 in which said first image correction module is configured to correct said acquired image prior to encoding by said image compressor, and wherein an indication of a region corrected by said first image correction module is stored in association with said corrected image.
- 20 13. A device according to claim 11 wherein said image acquisition device is configured to acquire a subsequent image after display of said corrected acquired image on said display.
- 25 14. A device according to claim 11 further comprising a second analysis-optimised filter configured to be activated after display of said first speed-optimized corrected acquired image on said display.
- 30 15. A device according to claim 1 operable to communicate with a second analysis-optimised filter configured to produce a second set of candidate red-eye regions for said stored image based on an analysis of said stored image and said first set of candidate red-eye regions.

16. A device according to claim 1 wherein said device is configured to partially decompress said stored image to produce an array of regions, each corresponding to one or more pixels of an originally acquired image, and wherein a second analysis-optimised filter is configured to operate only on regions of said array identified as corresponding to regions of said first speed-optimized set of candidate red-eye regions.
17. A device according to claim 16 wherein said second analysis-optimised filter is configured to fully decompress said identified regions and to analyse said regions at a pixel level.
18. A device according to claim 15 further comprising an image correction module configured to correct an acquired image based on one or both of said first and second set of red-eye candidate regions.
19. A device according to claim 15 wherein said second analysis filter is implemented in an image playback module configured to render said compressed image at a relatively high resolution.
20. A device according to claim 19 in which said image playback module is integrally implemented on said digital image acquisition device and wherein said image playback module is configured to display an image on said image display.
21. A device according to claim 19 in which said image playback module is configured to run on a remote device and wherein said digital image acquisition device is configured to communicate said compressed image and said associated first set of candidate red-eye regions to said remote device.
22. A device as claimed in claim 14 wherein said second analysis-optimised filter is optimised for accuracy.
23. A device according to claim 1, wherein the image acquisition device further comprises an image compressor for compressing said acquired image.

24. A device according to claim 1, wherein the image acquisition device further comprises a display for displaying an image stored on said acquisition device.
- 5 25. A device according to claim 1, further comprising a signal connection for transferring said image to a PC or other microprocessor-based device, or both, for further image processing of said encoded image.
26. A device as claimed in claim 1 further configured to store in said image store a  
10 sequence of at least one preview image.
27. A device as claimed in claim 26 further comprising a face detector configured to analyse said at least one preview image to provide information relating to candidate face regions of said at least one preview image to said first speed optimized filter.  
15
28. A device as claimed in claim 27 wherein said face detector is configured to operate in a search mode to detect candidate face regions and a tracking mode to predict and confirm candidate face regions.
- 20 29. A device as claimed in claim 26 wherein said at least one preview image is a sub-sampled version of the acquired image.
30. A device as claimed in claim 27 wherein said information comprises at least one of:  
i. a list of candidate face regions;  
25 ii. a set of data associated with the candidate face regions comprising a location the candidate face region within the image and statistical data derived from a history of the candidate face region; and  
a predicted location for the candidate face region within a subsequently acquired image.
- 30 31. An image acquisition device comprising:  
a) an imaging optic and detector for acquiring an image;  
b) a first speed optimized filter for producing a first set of candidate red-eye regions for an acquired image; and

c) an image encoder for encoding said acquired image.

32. A device according to claim 31 further comprising:

5 a second analysis-optimized filter configured to operate on said first set of candidate red eye regions and said acquired image.

33. A device according to claim 32 further comprising an image store memory for storing therein an encoded image in association with said first set of candidate red-eye regions for later image processing by said analysis-optimized filter.

10

34. A device according to claim 31 further comprising a display for displaying an image processed by said first speed-optimized filter.

35. A device according to claim 31, further comprising an image compressor for  
15 compressing said acquired image.

36. A device according to claim 31, further comprising a signal connection for transferring said image to a PC or other microprocessor-based device, or both, for further image processing of said encoded image.

20

37. A method of processing a digital image comprising:

a) filtering an acquired image with a first speed optimized filter to produce a first set of candidate red-eye regions;

b) encoding said acquired image; and

25 c) storing said encoded image in association with said first set of candidate red-eye regions for later image processing of said encoded image.

38. A computer program product comprising computer readable code for digital image artifact correction which when executed on an image processing apparatus is arranged to  
30 perform the steps of claim 37.

39. A digital image acquisition device, comprising:

(a) an imaging optic and detector for acquiring digital images including one or more preview images and a main image;

(b) a processor;

(c) a face detector module for programming a processor to analyze the one or more preview images to ascertain information relating to candidate face regions therein;

(d) an image generating module for programming the processor to generate a sub-sampled version of the main image; and

(e) a first speed-optimized red-eye filter for programming the processor to produce a first set of candidate red-eye regions in a sub-sampled version of the main image based on the candidate face region information provided by the face detector.

40. The device of claim 39, further comprising an image encoder for encoding said acquired image.

41. The device of claim 39, further comprising an image store memory for storing therein said encoded image in association with said first set of candidate red-eye regions for later image processing of said encoded image.

42. The device of claim 39, further comprising an analysis-optimized red eye filter and an image store memory, wherein the image store memory is for storing therein the main image in association with said first set of candidate red-eye regions for later image processing of a full resolution version of the main image by said analysis-optimized red-eye filter.

43. The device of claim 39, further comprising a display for displaying an image processed by said first speed-optimized red-eye filter.

44. The device of claim 39, further comprising an image compressor for compressing said acquired image.

45. The device of claim 39, further comprising a signal connection for transferring said image to a PC or other microprocessor-based device, or both, for further image processing of said encoded image.



46. The device of claim 39, wherein the face detector comprises a search module for detecting candidate face regions and a tracking module for predicting and confirming candidate face regions.

5 46. The device of claim 39, wherein the one or more preview images comprises a sub-sampled version of an acquired image.

47. The device of claim 39, wherein the candidate face region information comprises:

- (i) a list of one or more candidate face regions;
- 10 (ii) a set of data associated with one or more candidate face regions and statistical data derived from a history of the one or more candidate face regions; or
- (iii) a predicted location for one or more candidate face regions; or
- (iv) combinations thereof.

15 48. A processor-based method for filtering a red eye artefact from an acquired digital image based on program instructions embedded within digital memory, the method comprising:

- (a) acquiring one or more preview images;
- (b) analyzing the one or more preview images to ascertain information relating to
- 20 candidate face regions therein;
- (c) acquiring a main image;
- (d) analyzing a sub-sampled version of the main image; and
- (e) producing a first set of candidate red-eye regions in the main image based on the candidate face region information in the one or more preview images provided by the face
- 25 detector and on the analysis of the sub-sampled version of the main image.

49. The method of claim 48, further comprising encoding said main image.

30 50. The method of claim 49, further comprising storing said encoded main image in association with said first set of candidate red-eye regions for later image processing of said encoded main image.

51. The method of claim 50, further comprising image processing a full resolution version of the main image with an analysis-optimized red eye filter based only in part on information obtained in the previous analyzing.

5 52. The method of claim 51, further comprising correcting detected red eye artefacts within the main image, and storing a corrected main image.

53. The method of claim 48, further comprising displaying an image processed according to the analyzing of the sub-sampled version of the main image.

10

54. The method of claim 48, further comprising transferring the main image to a PC or other microprocessor-based device, or both, for further image processing along with information obtained in the previous analyzing.

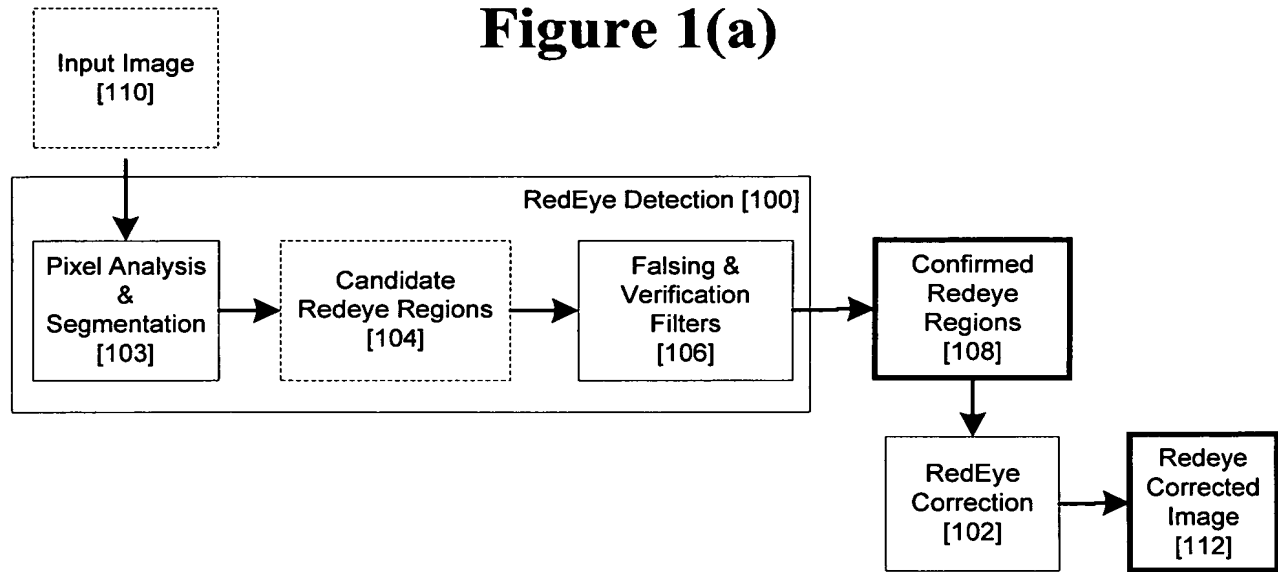
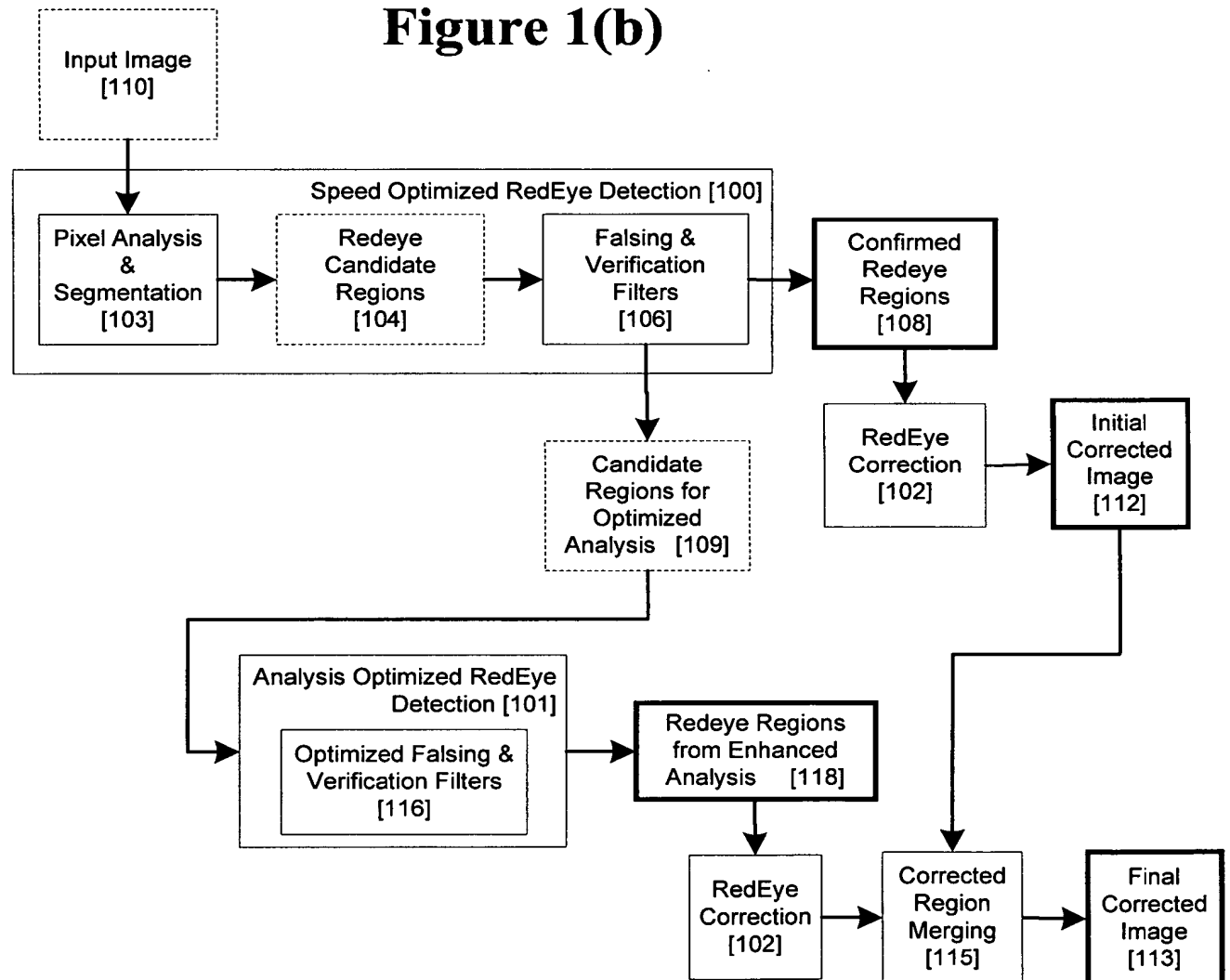
15 55. The method of claim 48, further comprising detecting candidate face regions and predicting and confirming candidate face regions.

56. The method of claim 48, wherein the one or more preview images comprises a sub-sampled version of an acquired image.

20

57. The method of claim 48, wherein the candidate face region information comprises:  
(i) a list of one or more candidate face regions;  
(ii) a set of data associated with one or more candidate face regions and statistical data derived from a history of the one or more candidate face regions; or  
25 (iii) a predicted location for one or more candidate face regions; or  
(iv) combinations thereof.

58. A computer program product comprising computer readable code for digital image artifact correction which when executed on an image processing apparatus is arranged to  
30 perform the steps of any of claims 48 to 57.

**Figure 1(a)****Figure 1(b)**

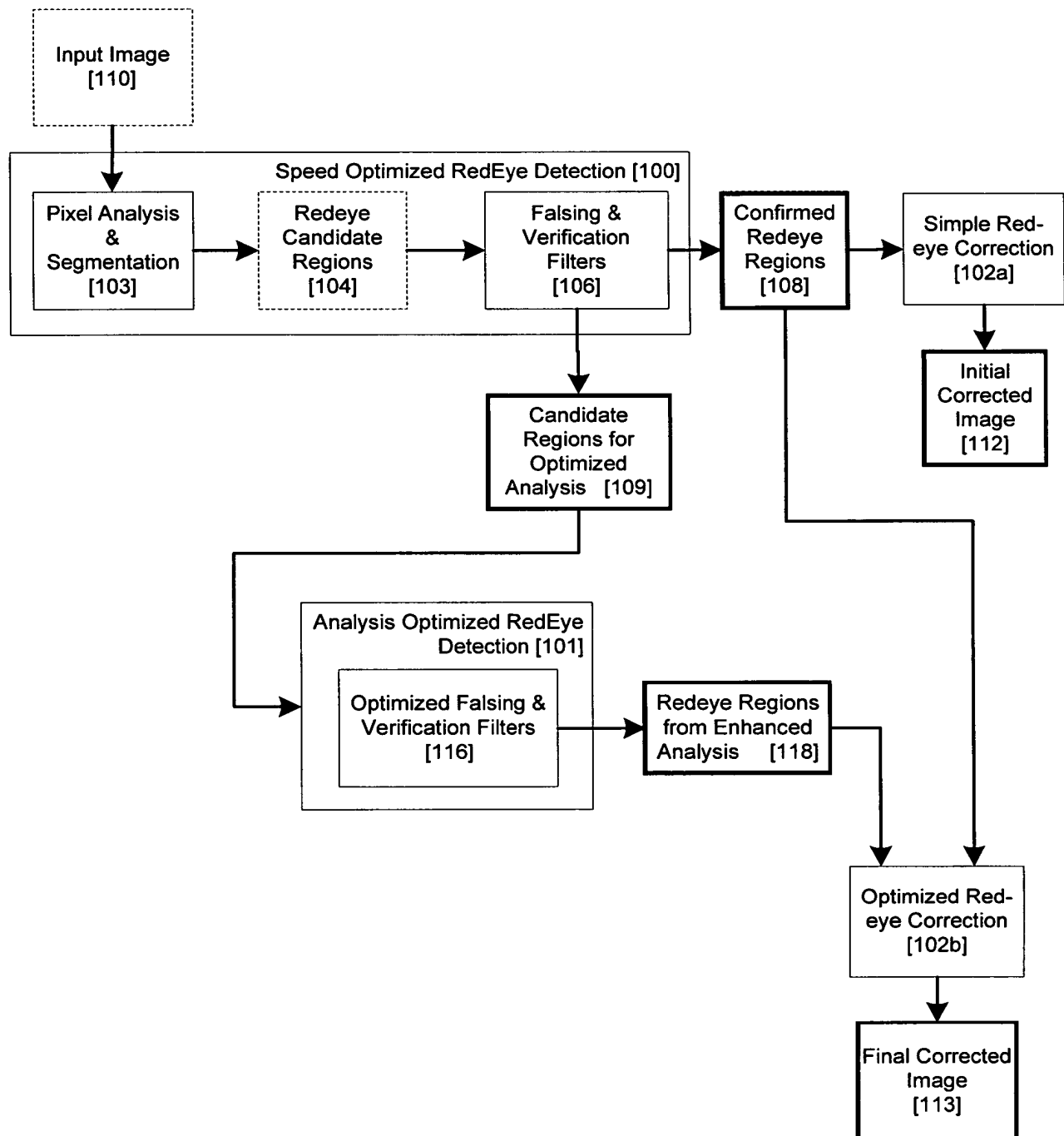
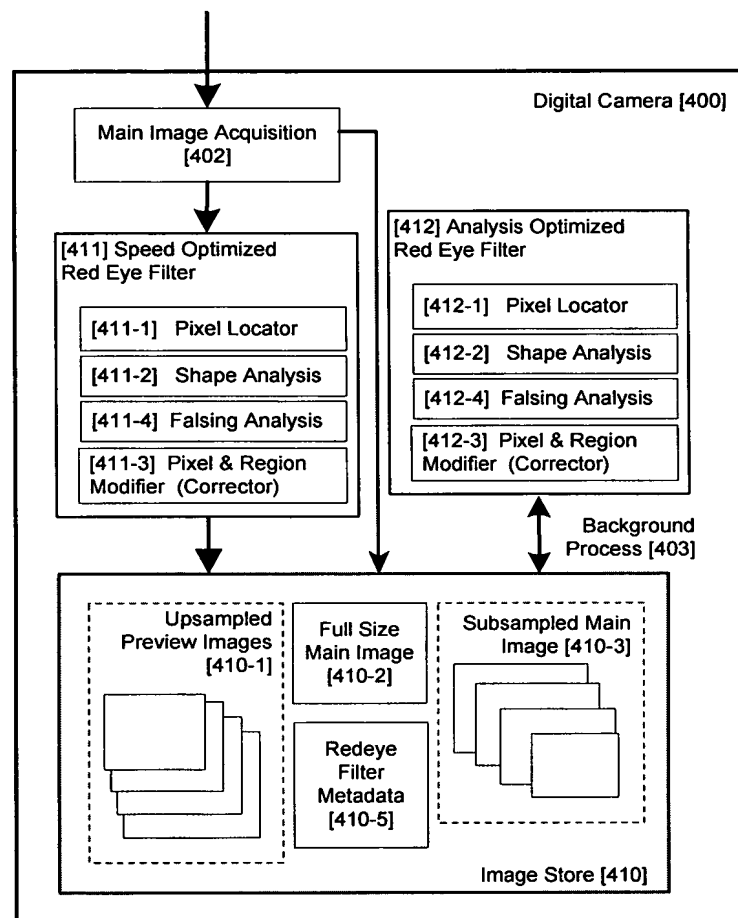
**Figure 1(c)**

Figure 2(a)



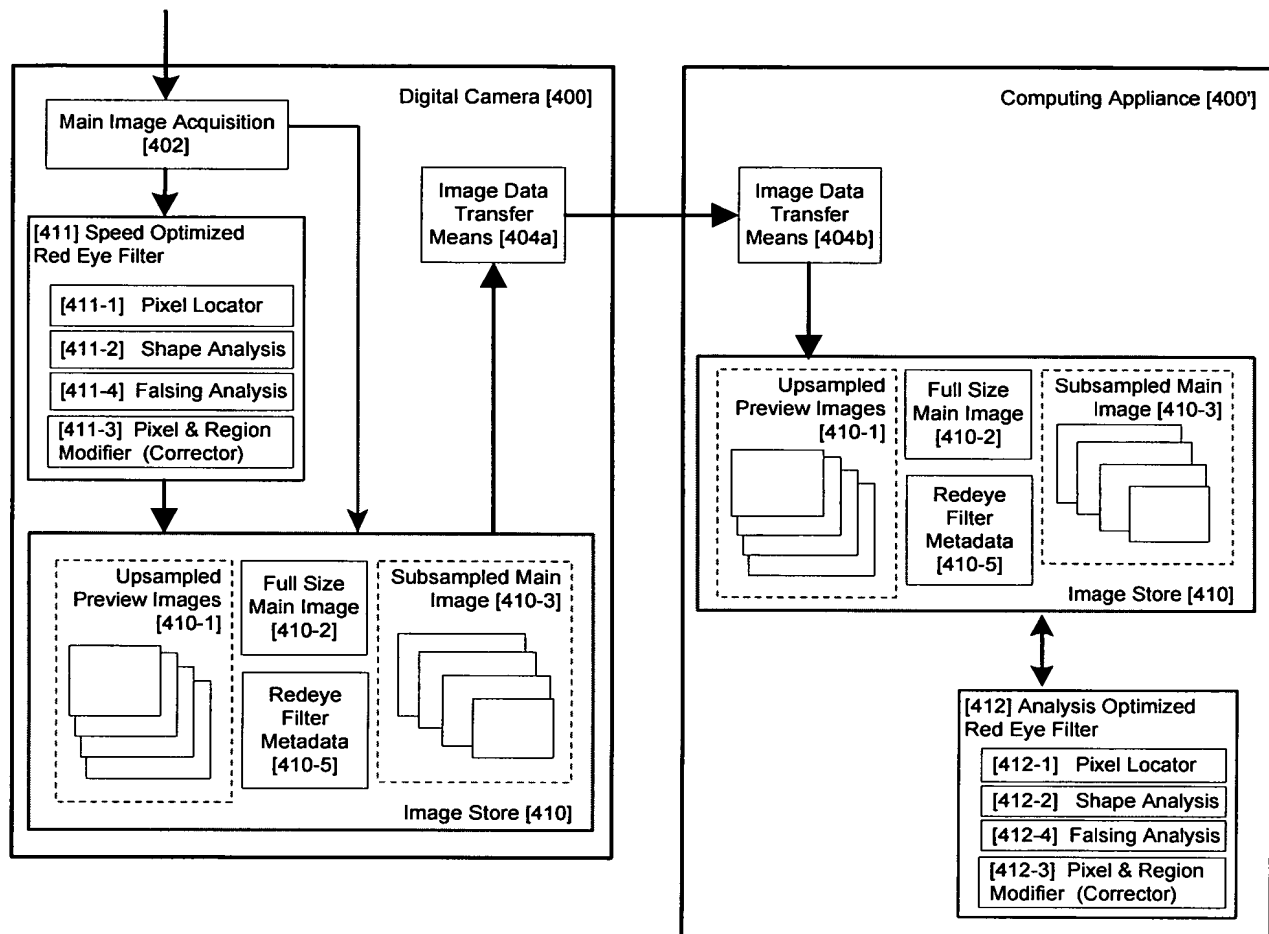


Figure 2(b)

Figure 3(a)

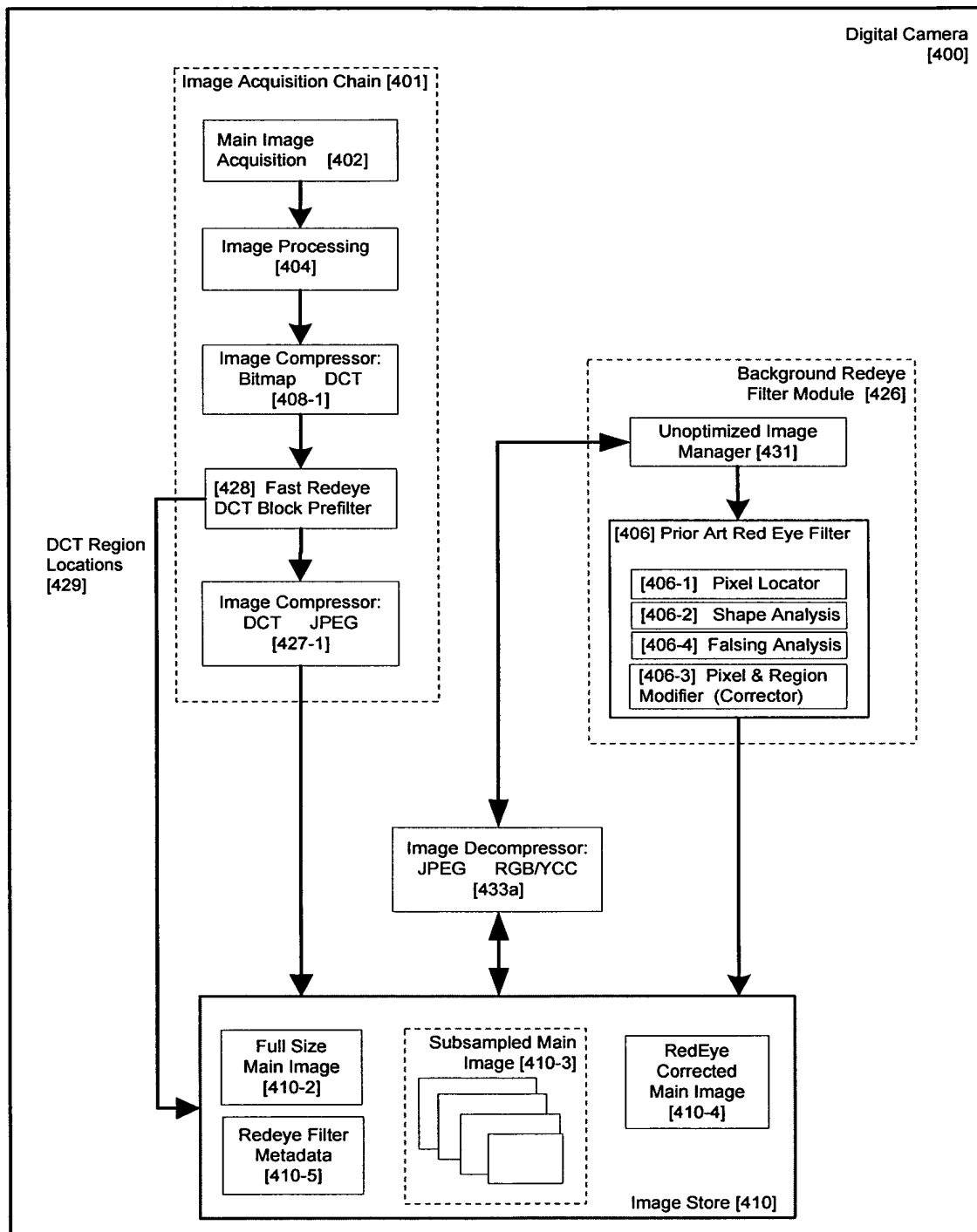


Figure 3(b)

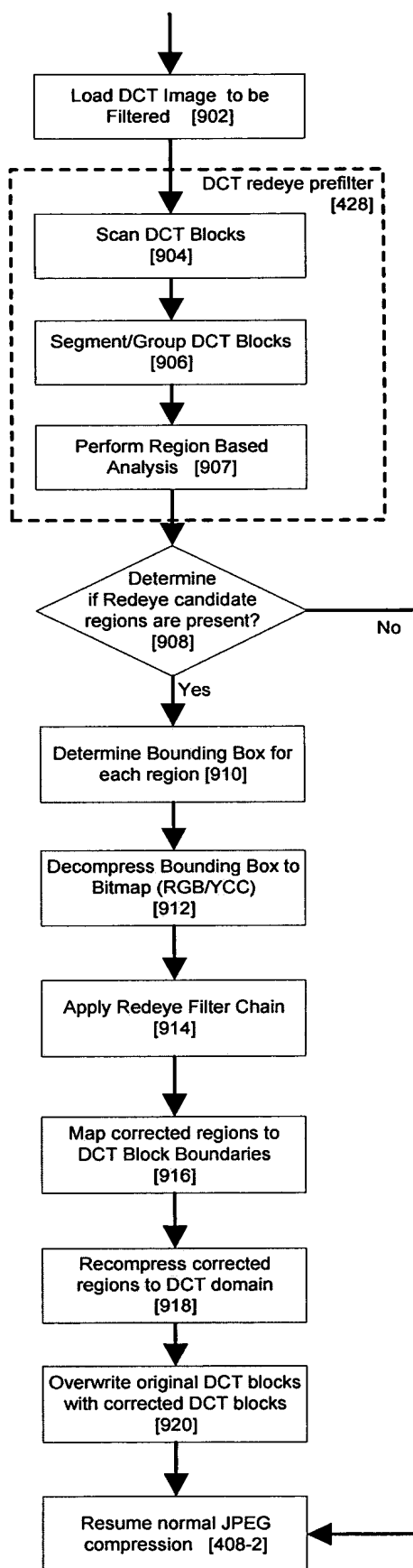




Figure 3(c)

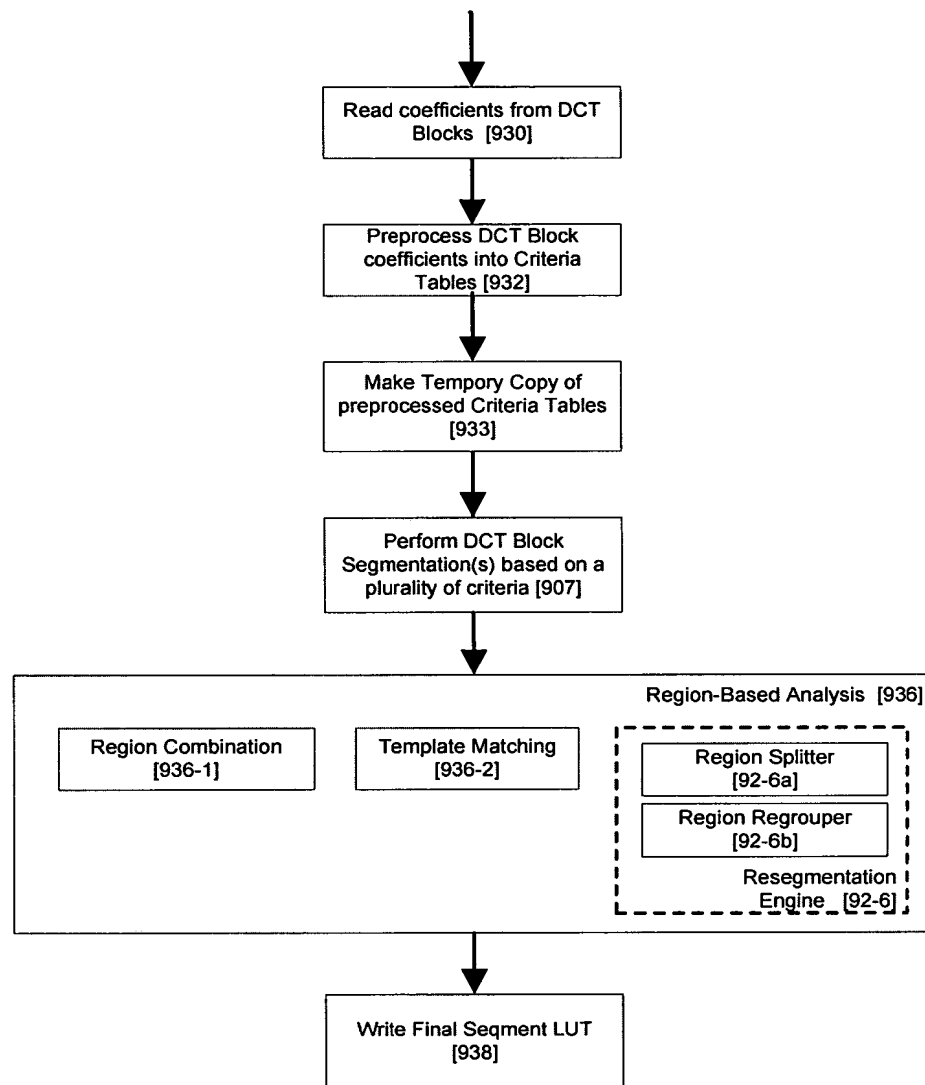


Figure 3(d)

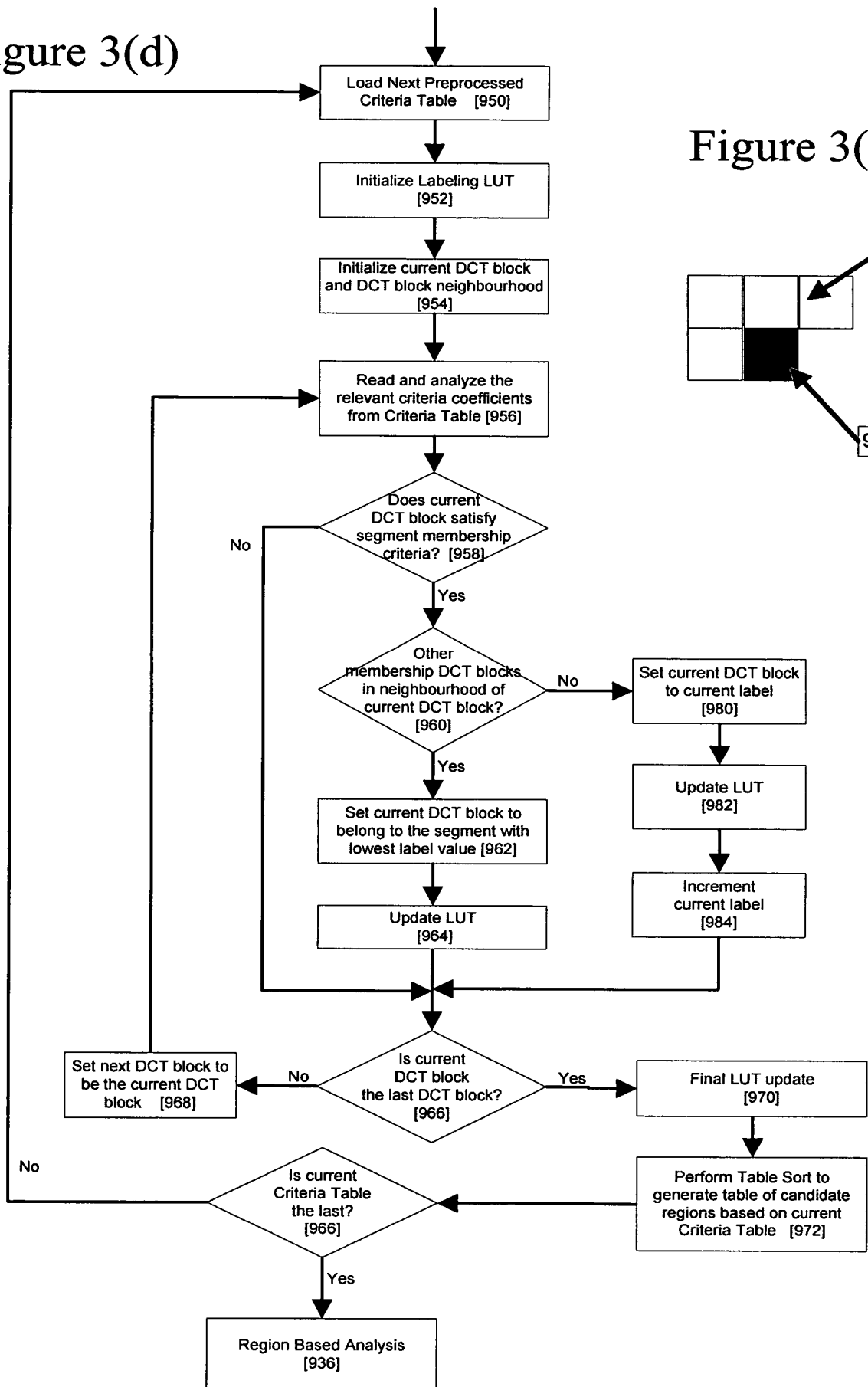
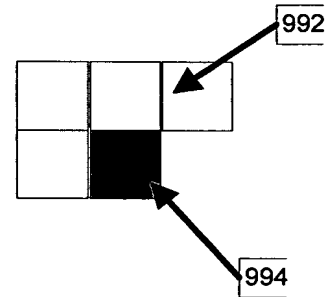


Figure 3(e)



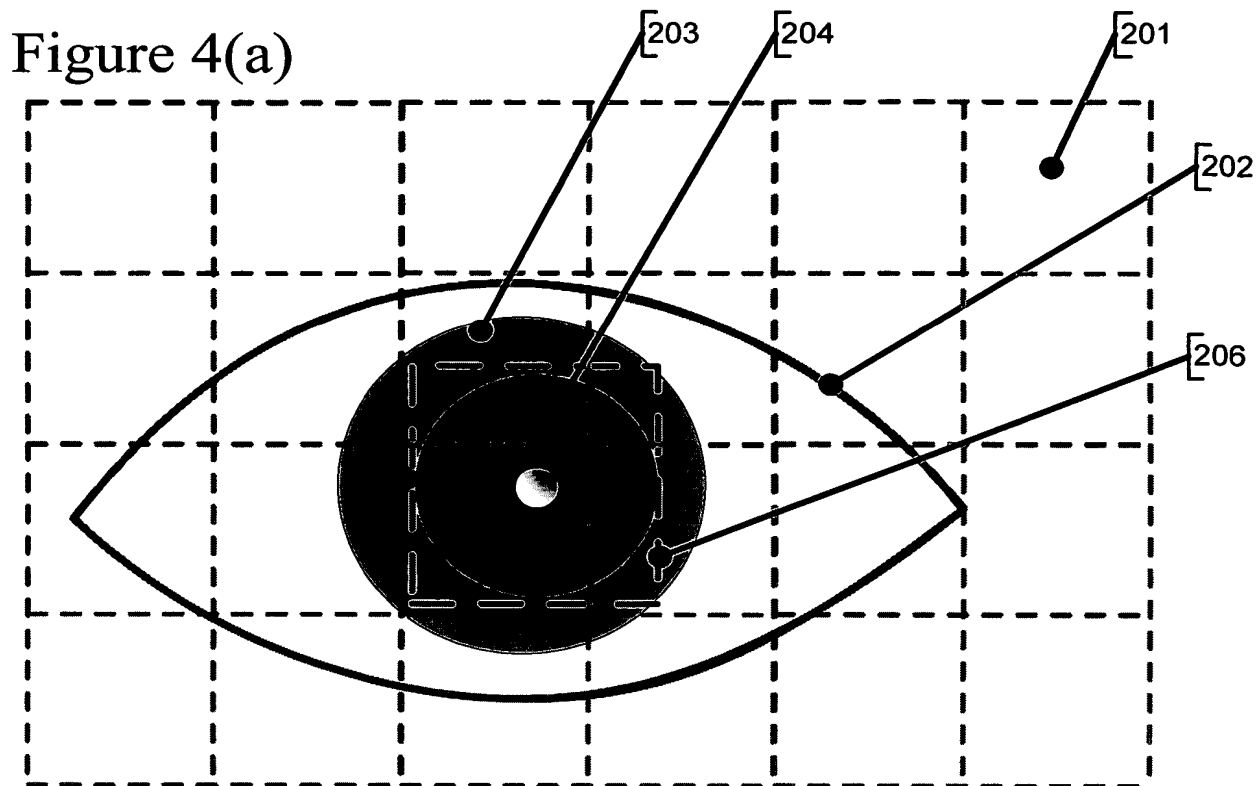


Figure 4(b)

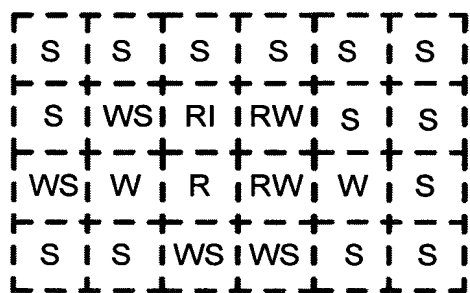


Figure 4(c)

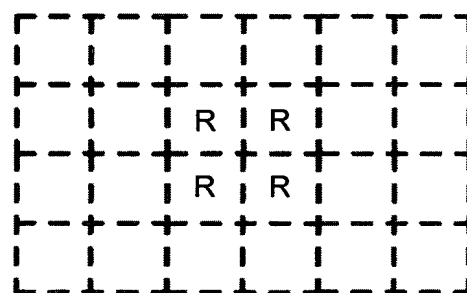


Figure 4(d)

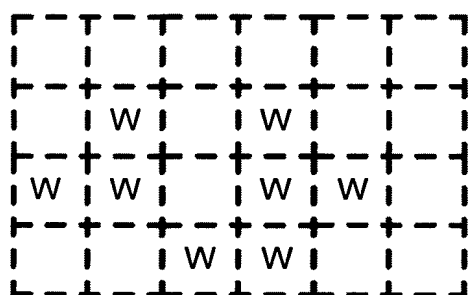


Figure 4(e)

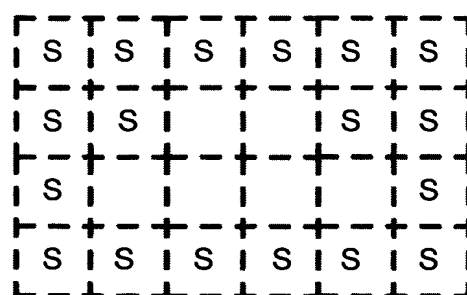
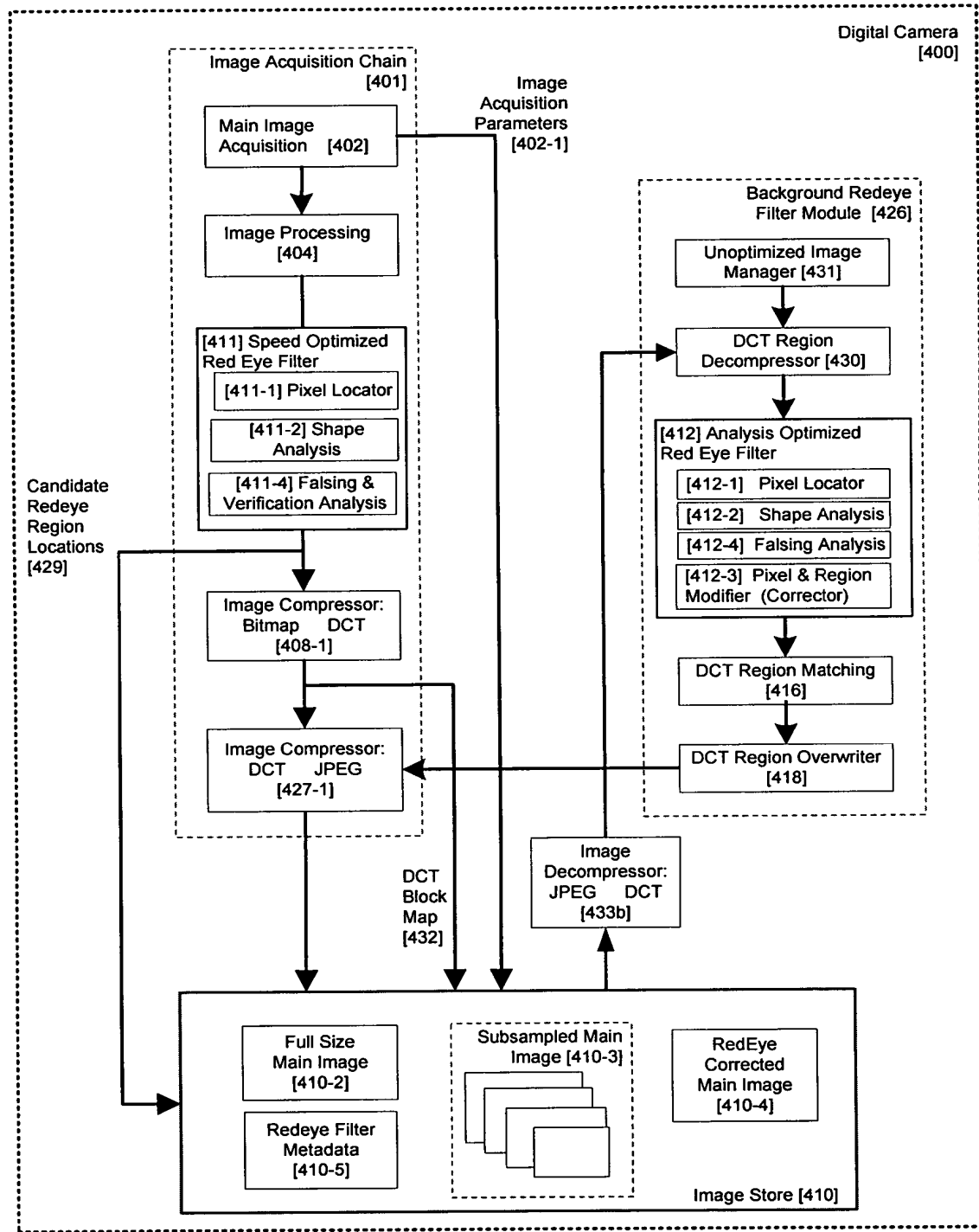


Figure 5



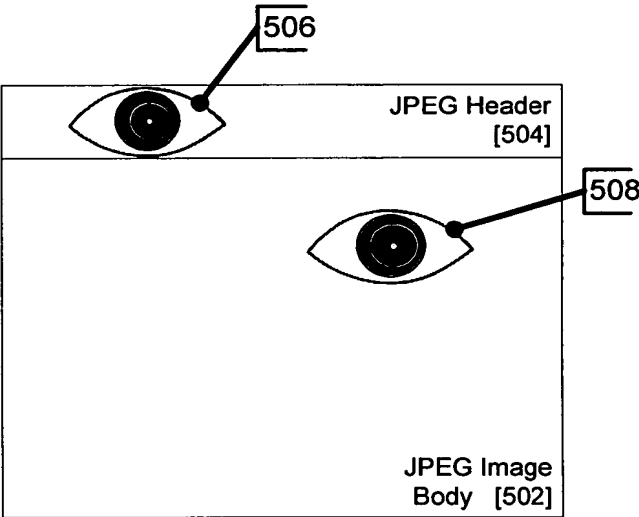


Figure 6(a)

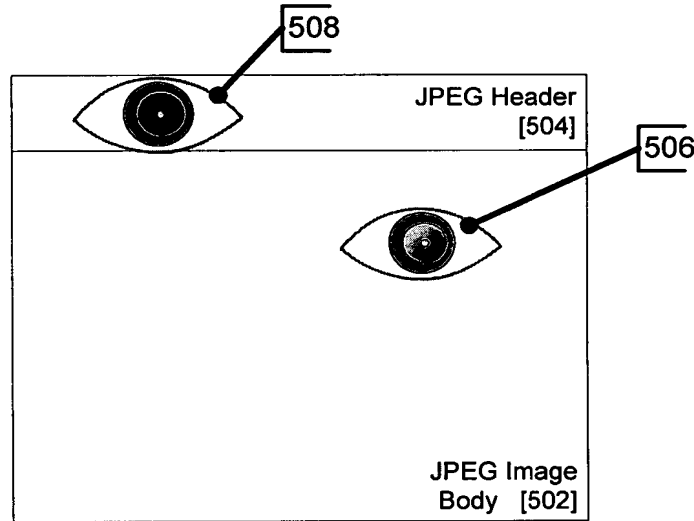


Figure 6(b)

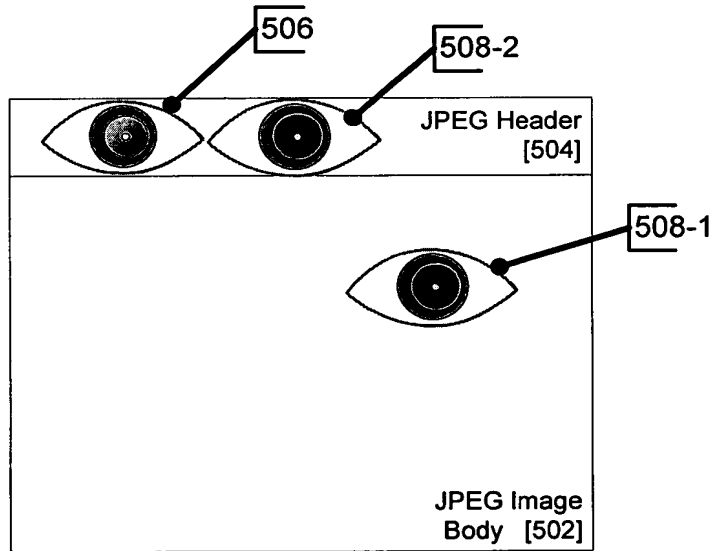
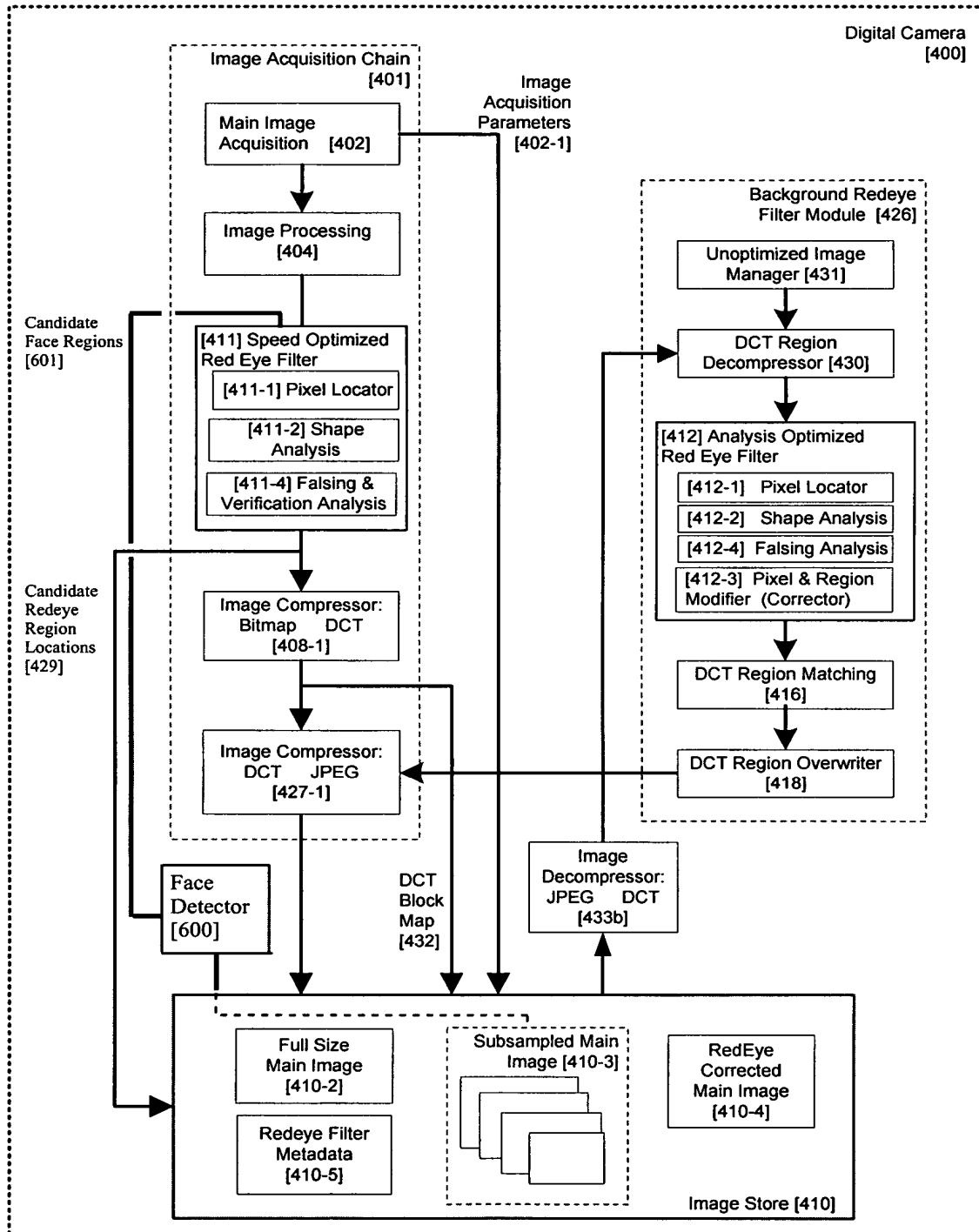


Figure 6(c)

Figure 7



## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2006/008358

A. CLASSIFICATION OF SUBJECT MATTER  
 INV. G06T7/00 G06T5/10

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
 G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC, COMPENDEX

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>US 2005/041121 A1 (STEINBERG ERAN [US] ET AL) 24 February 2005 (2005-02-24) cited in the application</p> <p>abstract            paragraphs [0006] - [0014], [0029] - [0031], [0059], [0070], [0072]; figure 1</p> <p style="text-align: center;">-----            -/--</p>	<p>1-3,            11-15,            18-29,            31-46,            48-56, 58</p>

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

\* Special categories of cited documents:

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

28 November 2006

Date of mailing of the international search report

05/12/2006

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2  
 NL - 2280 HV Rijswijk  
 Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
 Fax: (+31-70) 340-3016

Authorized officer

Eckert, Lars

## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2006/008358

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>SMOLKA B ET AL: "Towards automatic redeye effect removal" PATTERN RECOGNITION LETTERS, NORTH-HOLLAND PUBL. AMSTERDAM, NL, vol. 24, no. 11, July 2003 (2003-07), pages 1767-1785, XP004416063 ISSN: 0167-8655 sections "1. Introduction", "2.1.2. Skin segmentation in the HSV color space", "2.2. Morphological cleaning process", "2.3. Gray-scale conversion", "2.5. Redeye color replacement" section "3. Experimentation results"</p>	1-58
A	<p>CORCORAN P ET AL: "AUTOMATED IN-CAMERA DETECTION OF FLASH-EYE DEFECTS" IEEE TRANSACTIONS ON CONSUMER ELECTRONICS, IEEE SERVICE CENTER, NEW YORK, NY, US, vol. 51, no. 1, February 2005 (2005-02), pages 11-17, XP001240419 ISSN: 0098-3063 abstract section "III. A Practical In-Camera Algorithm", "IV. B. Code Memory Requirements", "IV. C. Execution Time Requirements"</p>	1-58



## INTERNATIONAL SEARCH REPORT

### Information on patent family members

International application No

PCT/EP2006/008358

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005041121 A1	24-02-2005	NONE	